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MAPPING INTRINSIC GROUNDWATER POLLUTION BY APPLYING THE DRASTICGOS MODEL USING GEOSPATIAL DATA: THE CASE OF THE GHRISS PLAIN (NORTHWESTERN ALGERIA)

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ABSTRACT

The Ghriss aquifer in northwestern Algeria is undoubtedly one of the country's most important reservoirs. Highly coveted by an ever-increasing domestic and agricultural demand, this potential has been confronted in recent years with a high pollution load from chemical inputs, nitrogen fertilizers and phytosanitary products, which are added to the discharge of poorly treated wastewater, leading to contamination risks for public health and disruption of local biodiversity. The aim of this study is to determine the degree of intrinsic vulnerability of the various forms of pollution introduced into the groundwater by the socio-economic activities carried out on the plain. The method is based on the universal DRASTIC model, supplemented by GOS parameters, coupled with a Geographic Information System (GIS) and geospatial data, obtained by remote sensing, enabling the various modeled parameters to be measured: water aquifer depth, net recharge, aquifer lithology, soil type, topography, impact of the vadose zone, aquifer hydraulic conductivity, land use and aquifer type. The cross-referencing of thematic maps highlights the emergence of groundwater pollution vulnerability classes (very high, high, medium, and low) and consequently the related causes. The results obtained and validated by the DRASTIC model indicate high vulnerability in 31% of the plain's alluvial aquifer, medium-sensibility zones in 68% and low-sensibility zones in 1%. As for the DRASTIC-GOS model, vulnerability to water pollution is classified into four distinct levels: low (0.04%), moderate (2.17%), high (1.21%) and very high (96.58%). In other words, the DRASTIC-GOS model reveals that the entire plain is threatened by anthropogenic pollution, confirming the good performance of this mapping approach for monitoring groundwater resources.

Keywords: DRASTIC; DRASTIC-GOS; Groundwater; Mapping; Pollution; Vulnerability.

1 INTRODUCTION

The arid nature of the Algerian territory, aggravated by recurrent and persistent drought since the 1980s, has led to water deficits of between 30% and 50%, depending on the geographical context of the catchment areas. In addition to the unpredictability of runoff and natural recharge of aquifers, water demand is concentrated in certain socio-economic centers with high water consumption.

Occupying an area of 1210 km^2, the Ghriss plain is part of this specific Algeria water stress problem, with a more severe crisis throughout the northwestern part of the country. The anthropogenic forcing of pumping to exploit this aquifer implicitly leads to a drop in hydrodynamic levels never before reached. Observation by piezometrics indicates drawdowns reaching tens of meters [1].

In addition, the many discharges of wastewater effluent from urban and industrial centers pose a serious threat to the quality of the aquifer's groundwater. Added to this is intensive farming using nitrogen fertilization and various chemical inputs to develop cropping systems. This aspect of contamination has been highlighted by nitrates now the major cause of pollution in groundwater reservoirs [2].

Several modelling approaches have been discussed, shedding light on the quantitative and qualitative aspects of the water in the Ghriss Plio-Quaternary aquifer. However, the cartographic interest in intrinsic groundwater pollution has often been overlooked, including by state water management bodies such as NWRA (National Water Resources Agency) and IWRMA (Integrated Water Resources Management Agency).

Intrinsic vulnerability, the subject of this study, is defined by several authors according to the physical and natural conditions of the environment. Or according to susceptibility to contamination [3]. It is the ability of an aquifer to absorb or diffuse a pollutant transported by water [4]. It is also seen as the hydrogeological conditions offered by an aquifer in terms of the penetration of contamination from the soil surface. Finally, Vrba and Zaporozed [5] consider it to be an intrinsic property of a groundwater body in relation to its sensitivity to surrounding anthropogenic and natural impacts.

Faced with this situation, and with a view to sustainable management of water resources, this study focuses on mapping the vulnerability of the Ghriss aquifer to intrinsic pollution, with a view to detecting and spatializing in sensitive areas and providing the necessary solutions. The approach is based on DRASTIC modeling, defining the dynamics and sensitivity of the environment to pollution, with the aim of providing an effective state by integrating land-use factors [6].

The aim is to test this numerical tool to optimize the exploitation of the Ghriss aquifer, which is of vital interest to the region's socio-economic development, with a view to providing the manager with a tool capable of controlling the quantitative and qualitative risk of groundwater, particularly its vulnerability to the risk of pollution, in line with the process of water contamination and the transmission of undesirable effects [7]. Determination of the percentage of groundwater vulnerability [8] and validation of the results are carried out using standard classification indices [9]. This indexing method is considered the most relevant to field realities [10].

2 CHARACTERIZATION OF THE STUDY AREA

Located in north-western Algeria, the Ghriss plain is part of the Macta watershed, Oued Fekan sub-basin. It lies between 35°07′ and 35°31′ north latitude and 0°0′56″ to 0°26′ longitude. Geomorphologically, it covers an area of 1185km^2, with a flat topography, encircled by moderately elevated relief, bounded by the Béni Chougrane to the north, the Saïda Mountains to the south, the Bouhanifia hills to the west, and the Mana basin to the east. The basin, with its Quaternary formation, is conducive to the formation of the water aquifer of regional importance (Figure. 1).

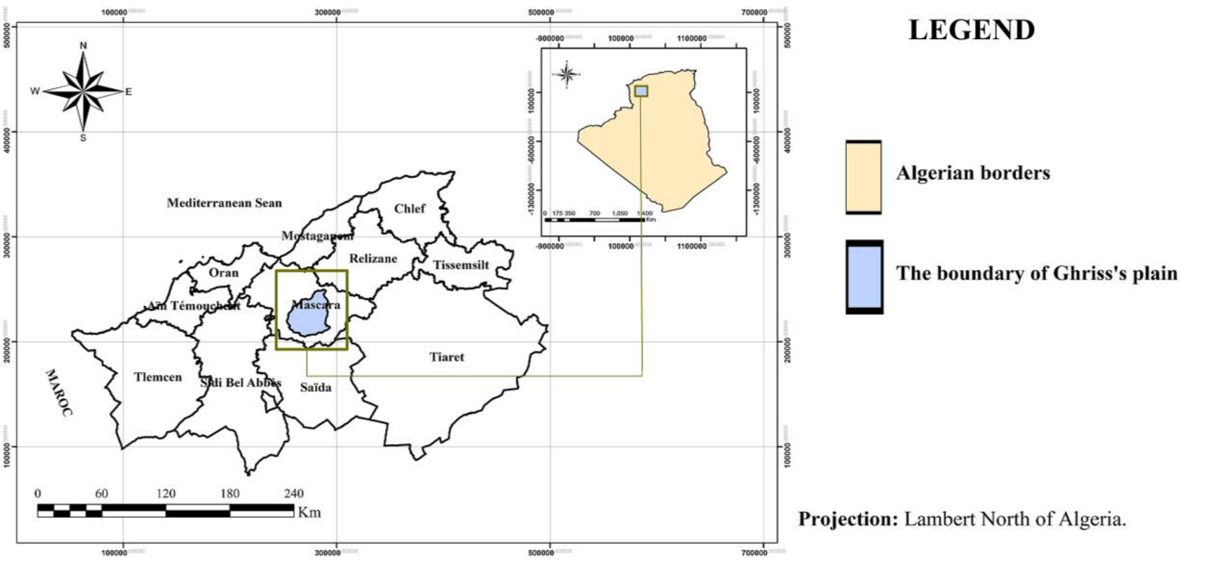

Figure 1. *Geographical location of the study area (Ghriss-Mascara plain)*

The geological framework of the study area, as defined by the National Water Resources Agency [1] highlights four structures, defined as follows:

- Edge of the Béni Chougrane Mountains, elongated in a circular arc, running south-southwest and North-northeast., highly folded, with a Cretaceous backbone and Superior Miocene overlay.
- Edge of the Saïda Mountains, along the plain to the south, in the form of the Kimmeridgian Upper Jurassic. Generally, they were composed of resistant bedrock.
- Astien formation in the north of the city of Mascara. This formation consists of Calcareous Sandstone, yellow Marl and Sand.
- Edge of Bouhanifia Mountains with the position of the Mio-Pliocene formation, which is composed of Lacustrine Limestone, Clay and Conglomerates.
- To the south of the plain are plantations of Superior Jurassic and Pliocene formations.
- Central formation of the plain, a collapsed basin, marked by the flexure of the Neogene strata, which is continued by the present and recent Quaternary alluvium (Figure.2)

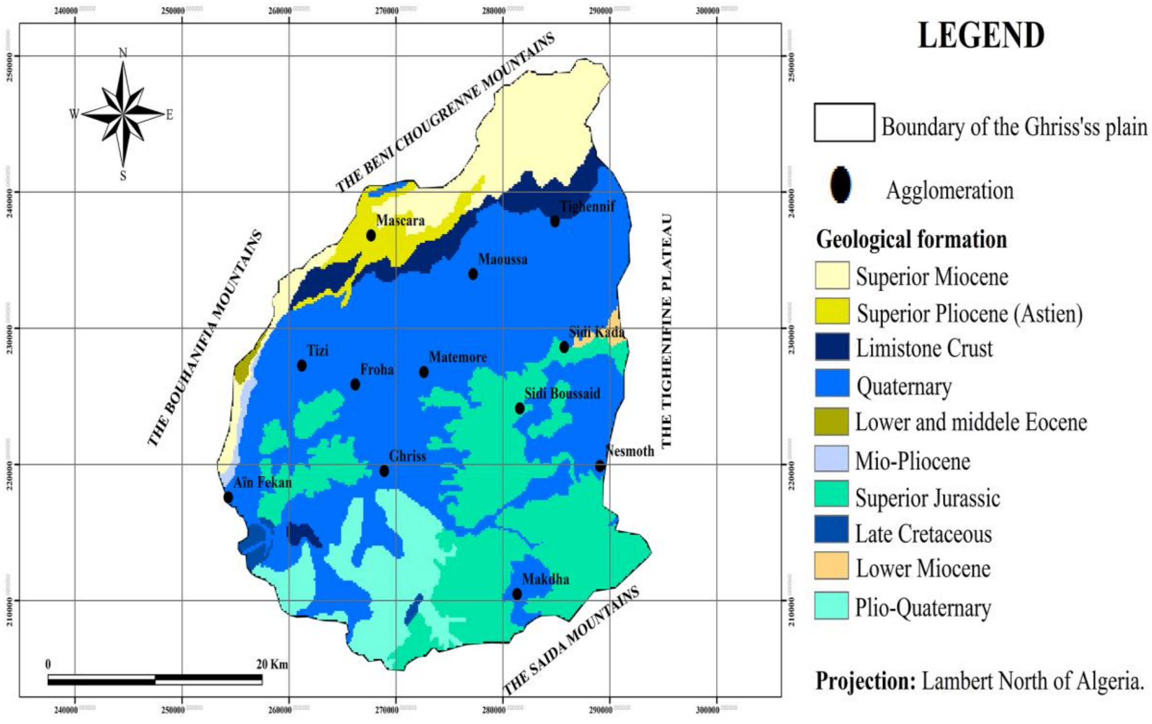

Figure 2. *Geological structure of the Ghriss plain [1]*

Climatically, the area has a dry period that is longer than the wet period, with average annual rainfall estimated at 450mm/year, and a climatic aridity index of 0.68. In 1997, the piezometric level of the plain was 60m lower than the rainfall. Conversely, since 1998, exploited groundwater flows have been more than recorded rainfall [11].

The hydrographic network draining part of the study area is made up of two temporary watercourses coming from the southern flank of the Béni Chougrane massif. These are Oued Maoussa and Oued Froha. However, the main surface water resources for agricultural use come from the Ouizert dam, located in the southern part of the plain.

The hydrogeology of the Ghriss groundwater is characterized by an aquifer complex of three aquifers, resting on a bedrock of Miocene Blue Marl, principally the Plio-Quaternary aquifer, which varies in thickness from 40 to 100m. This is the main water resource in the region, with piezometric varying according to rainfall year. The water aquifer's natural outlet is south-westerly flow towards the Ain Fekan springs. The center of the plain (Matmore-Maoussa) is about Lacustrine Limestone formation, with the highest abstraction rates in the study region [12].

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On the whole, the water aquifer is exploited by individual, shallow boreholes, which has led to pumping being forced for both agricultural needs and urban drinking water supplies. This has manifested itself in a race to pump through the aquifer zones of the plain, where there are almost 5000 water points. The established storage coefficient is between [0.1 and 0.25], which means that the free-water aquifer has porosity. Permeability (K) is estimated between 10^{-7} and 10^{-6} m/s [12].

The volume of water extracted is estimated at 88hm^3/year, whereas groundwater inflow is around 56hm3/year, confirming the extent of the phenomenon of overexploitation, exceeding the optimum groundwater abstraction threshold [1]. The seven treatment plants supply an appreciable quantity of water for irrigated plots in the study region, but their purification performance in terms of influential parameters (MS, BOD_5, COD, NO_3^-, NH_4^+, and TP) indicates a lack of treatment compared to accepted standards, as shown in table 1 [13]. All treatment plants are located close to agricultural land (Figure 3). The migration of pollutants through subsoil horizons favors the contamination of groundwater.

Table 1. *Treatment efficiency of wastewater treatment plants across the study area*

Physico-chemical parameters	Ghriss WWTP (mg/l)	Bouhanifia WWTP (mg/l)	Hacine WWTP (mg/l)	Tizi WWTP (mg/l)	Mohamadia WWTP (mg/l)	Froha WWTP (mg/l)	Average yield (%)
SM	87	70	84	86	54	53	72
BOD_5	87	67	82	67	49	73	71
COD	88	69	89	53	44	83	71
NO_3^-	56	54	55	54	40	47	51
NH_4^+	46	50	44	54	55	57	51
TP	40	31	40	35	25	35	34

WWTP (Wastewater treatment plant); SM (Suspended Matter); BOD_5 (Biochemical Oxygen Demand for 5 Days); COD (Chemical Oxygen Demand); NO_3^- (Nitrates); NH_4^- (Ammoniacal nitrogen); TP (Total Phosphates).

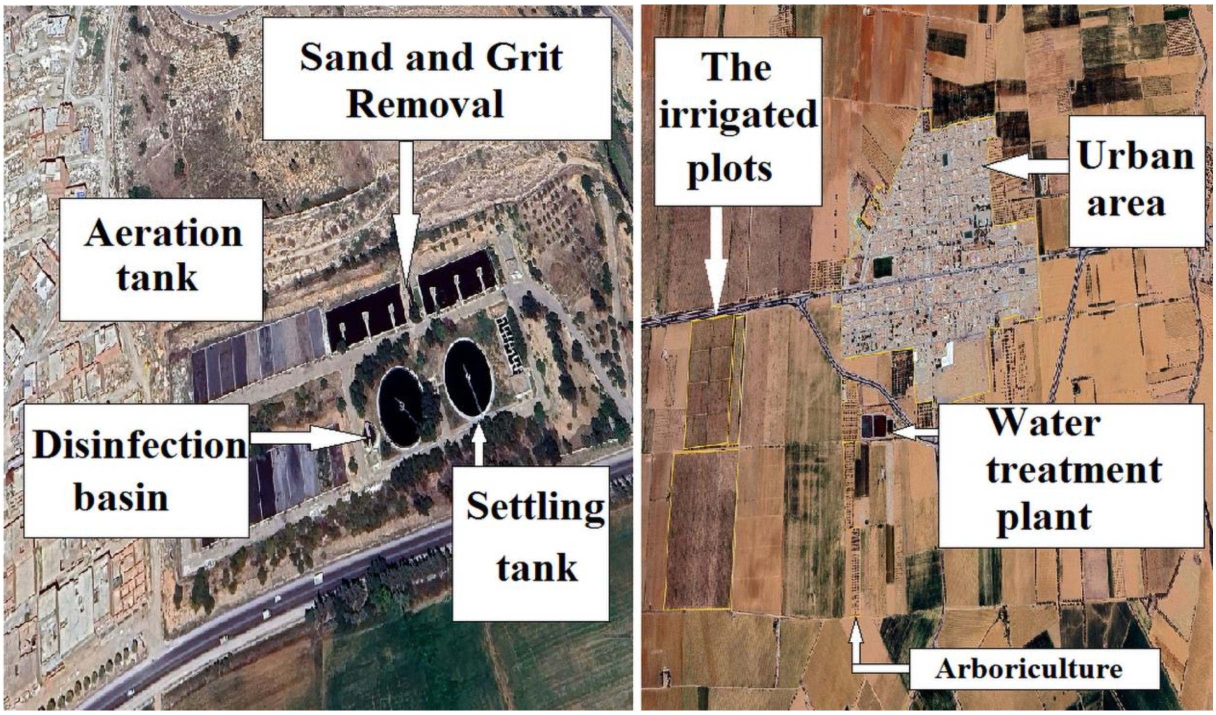

Figure 3. *Location of Water Treatment Plants in irrigated trees*

3 MATERIELS AND METHODS

3.1 Material used

All acquired data was processed using a Geographic Information System (GIS). The acquisition method consisted in digitizing and interpolating the acquired data in raster format (Table 2).

Table 2. *Data sources and acquisition methods used*

DATA TYPE	SOURCES	SCALE	ACQUISITION MODE	FORMAT	USED TO PRODUCE
WELL AND BOREHOLE DATA	Mascara DWR Inventory		Interpolation	Raster	Depth parameter "D"
RAINFALL	NMO of Mascara		Interpolation	Raster	Recharge parameter "R"
WATER ANALYSIS (NO_3^-)	NWRA of Oran/WA of Mascara		Interpolation	Raster	Pollution sources
THE LOGS OF THE DRILLING	DWR of Mascara		Digitalization	Raster	Saturation parameter "A"
SOIL MAP OF ALGERIA	INC, N.I.31-NO (1927-1938)	Africa 1:500000	Digitalization	Raster	Soil parameter "S"
TOPOGRAPHY MAP AT 10M EQUIDISTANCE	Satellite im11age			Raster	Slope parameter "T"
GEOLOGY MAP OF MOSTAGANEM	NWRA, NI-31-XIX	Algeria 1:200000	Digitalization	Raster	Unsaturated zone parameter "I"
PUMPING TESTS AND TRANSMISSIVITY MAP	Borehole reports (DWR/Mascara)		Interpolation	Raster	Aquifer permeability parameters "C"
HYDROGRAPHY	Topographic map			Raster	Infiltration zone
LAND USE	Satellite images of the Arzew STC			Raster	Source of pollution and determination of cultivated area

3.2 The DRASTIC model

Numerous methods for determining groundwater vulnerability have been developed worldwide, using physical, chemical and biological models combined with weightings between different criteria. In this study, vulnerability mapping is approached using the DRASTIC method, with index and weighting.

Developed in 1987 by EAP (Environmental Protection Agency), the DRASTIC method of Depth, Recharge Aquifer, Soil, Topography, Impact of the vadose, and Conductivity is designed to study the vulnerability of groundwater to aquifer pollution. To convert these multi-source parameters into thematic maps in (Figure.4), a weight between 1 and 5 is assigned to each parameter, reflecting its importance in the contaminant process [6].

The vulnerability index (VI) is obtained by summing the products of each rating by their weight according to equation (1) below [14]:

$$VI = [(D_C \times D_P) + (R_C \times R_P) + (A_C \times A_P) + (S_C \times S_P) + (T_C \times T_P) + (I_C \times I_P) + (C_C \times C_P)] \quad \textbf{\textit{(1)}}$$

Where: p = parameter weight (varies from 1 to 5); c = Associated rating (varies from 1 to 10) in table 3.

From the summary map, we deduce the vulnerability classes (high, medium, low) and consequently the main causes of pollutant contamination in the aquifers. Note that the DRASTIC index (DI) varies between71 to 156, hence its classification into four categories according to the standard DRASTIC index classification of Aller et al., [6] or into three (3) distinct categories according to the classification of Engel et al., [9]. For our case study, we opted for the most recent classification, that of Engel et al., [9].

Table 3. *Classes and ratings of the seven DRASTIC parameters* [15]

D: DEPTH OF WATER AQUIFER (M)		**R: NATURAL LOAD (MM)**	
VALUES (m)	**RATING**	**VALUES (mm)**	**RATING**
0 – 1.5	10	**> 22.5**	9
1.5 – 4.5	9	**17.5 – 22.5**	8
4.5 – 9	7	**10 – 17.5**	6
9 – 15	5	**5 – 10**	3
15 – 22	3	**0 – 5**	1
22.5 – 30	2		
>30	1		
A: NATURE OF THE SATURATED ZONE		**S: Soil type**	
SATURATED ZONE	**RATING**	**SOIL**	**RATING**
KARSTIC LIMESTONE	10	**THIN OR ABSENT**	10
SAND AND GRAVEL	8	**SAND**	9
MASSIVE SANDSTONE	6	**SANDY LOAM**	6
ALTERED METAMORPHIC	4	**SILT**	4
METAMORPHIC	3	**SILTY SILTS**	3
MASSIVE SAND	2	**CLAYS**	1
T: TOPOGRAPHY (SLOPE)		**I: LITHOLOGY OF THE VADOSE LAYER**	
VALUES (°)	**RATING**	**LITHOLOGY**	**RATING**
0 – 1	10	**KARSTIC LIMESTONE**	10
1 – 3.5	9	**SAND AND GRAVEL**	9
3.5 – 7	5	**SAND AND GRAVEL WITH SILT AND CLAY**	8
7 – 10	3	**SANDSTONE**	6
>10	1	**LIMESTONE**	6
C: PERMEABILITY		**SILT AND CLAY**	1
VALUES (m/s)	**RATING**		
>9.5×10^{-4}	10		
4.7×10^{-4} – 9.4×10^{-4}	8		
32.9×10^{-5} – 4.7×10^{-4}	6		
14.7×10^{-5} – 32.9×10^{-5}	4		
4.7×10^{-5} – 14.7×10^{-5}	2		
4.7×10^{-7} – 4.7×10^{-5}	1		

3.1 DRASTIC-GOS model description

The proposed DRASCTIC-GOS model is used to investigate the possible risks of vertical contamination of aquifers by pollutants of agricultural origin. Its application is based on the development of the seven (7) parameters of the DRASTIC method, to which are added two parameters relating to aquifer typology (G) and land use (OS).

This will make it possible to track the circulation of pollutants from the earth's surface to the piezometric surface of the groundwater aquifer. In this way, the DRASTIC-GOS vulnerability index is calculated as the sum of the weights and scores of each parameter, calculated by equation (2), taking into account groundwater depth (D), recharge (R), aquifer lithology (A), soil type (S), slope (T), vadose zone impact (I) and aquifer permeability (C), all assigned the same DASTIC weights and scores.

$$VI = [(D_C \times D_P) + (R_C \times R_P) + (A_C \times A_P) + (S_C \times S_P) + (T_C \times T_P) + (I_C \times I_P) + (C_C \times C_P) + (G_C \times G_P) + (OS_C \times OS_P)] \qquad \textbf{(2)}$$

The groundwater typology parameter (G) is considered to represent the ease with which pollutants can be transmitted to groundwater. It is more important in alluvial aquifers and relatively less so in confined aquifers. The thematic map of this parameter is produced by digitizing the boundaries of the various aquifers located in the study area as mentioned in the Mostaganem aquifer map [16]. The weight of this parameter G is estimated at 3 in the case of our study area. By way of comparison, table 4 defines the classification used to assign the ratings of typical aquifer parameters, i.e. the vulnerability estimation by the GOD method [17].

Table 4. *Tablecloth type classes and assigned* weights *[17]*-GOD *method*

TYPE OF WATER AQUIFER	RATING
NO AQUIFER	0
ARTESIAN CAPTIVE	0.1
CAPTIVE	0.2
SEMI-CAPTIVE	0.3
SEMI-FREE	0.5
FREE	1
WEIGHT	3

The land cover parameter (OS) is determined on the basis of satellite image processing. The coastline classification of the represented land use factor (LU). These factors are identified by multiplying the assigned values by 10. These factors correspond to the land use ratings of the SI (Susceptibility Index) method. The values obtained vary from the least vulnerable to the most vulnerable. They range from 0 to 100. In our case study, the value obtained was five (5). The weight assigned to this parameter is in line with the influence of pollutant transmission on the groundwater (Table 5).

Table 5. *Land use classes and weights assigned according to Cover C.L [18].SI method*

LAND COVER CLASSES	FACTOR VALUE (LU)
INDUSTRIAL LANDFILL, GARBAGE DUMP, MINE	100
IRRIGATED PERIMETERS, RICE PADDIES, IRRIGATED AND NON-IRRIGATED ANNUAL CROPS	90
QUARRY, SHIPYARD	80
ARTIFICIAL COVERD AREAS, GREEN ZONES, CONTINOUS URBAN AREAS	75
PERMANENT CROPS (VINEYARDS, ORCHARDS, OLIVE GROVES, ETC.)	70
DISCONTINUOUS URBAN AREAS	70
PASTURES AND AGRO-FORESTRY AREAS	50
AQUATIC ENVIRONMENTS (MARSHES, SALT PANS, ETC.)	50
FORESTS AND SEMI-NATURAL AREAS	0
WEIGHT OF THE LAND COVER PARAMETER	5

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The estimated DRASTIC-GOS vulnerability index ranges from 74 to 636. The proposed map reflects an increase in vulnerability classes (very high, moderate, high, and low) compared with those proposed by Engel et al [9]. The latter deduces a greater risk of vertical pollution in the plio-quaternary aquifer of the study area (see annexes 1a, 1b, 1c, 1d, 1e and 1f).

4 DISCUSSION OF INTRINSIC VULNERABILIRY MAPPING

4.1 Application of the DRASTIC method

These indices are used to draw up a vulnerability map for the Plio-Quaternary water aquifer. Based on the classification proposed by Engel et al., [9]. The DRASTIC indices give values ranging from 74 to 156. For our case study, we can easily observe the three (3) sensitivity classes, distributed as follows in figure 5 and 6:

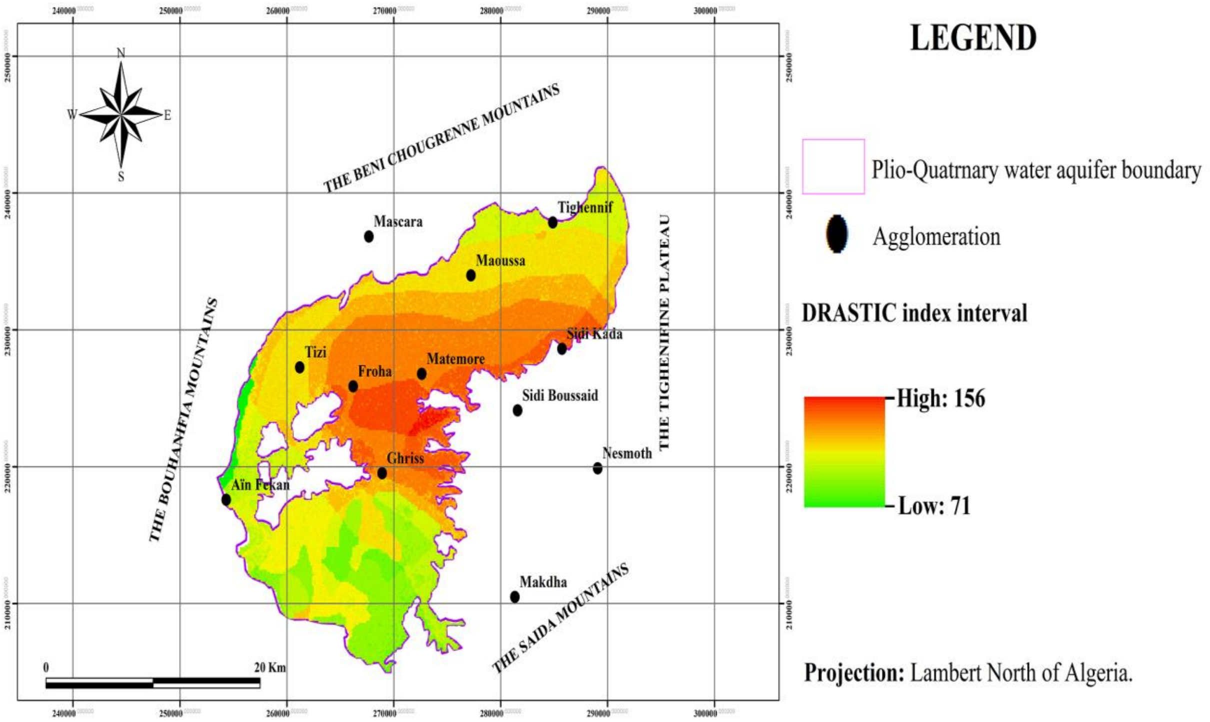

Figure 5. *Map of the DRASTIC index interval in the Plio-Quaternary aquifer of the Ghriss plain*

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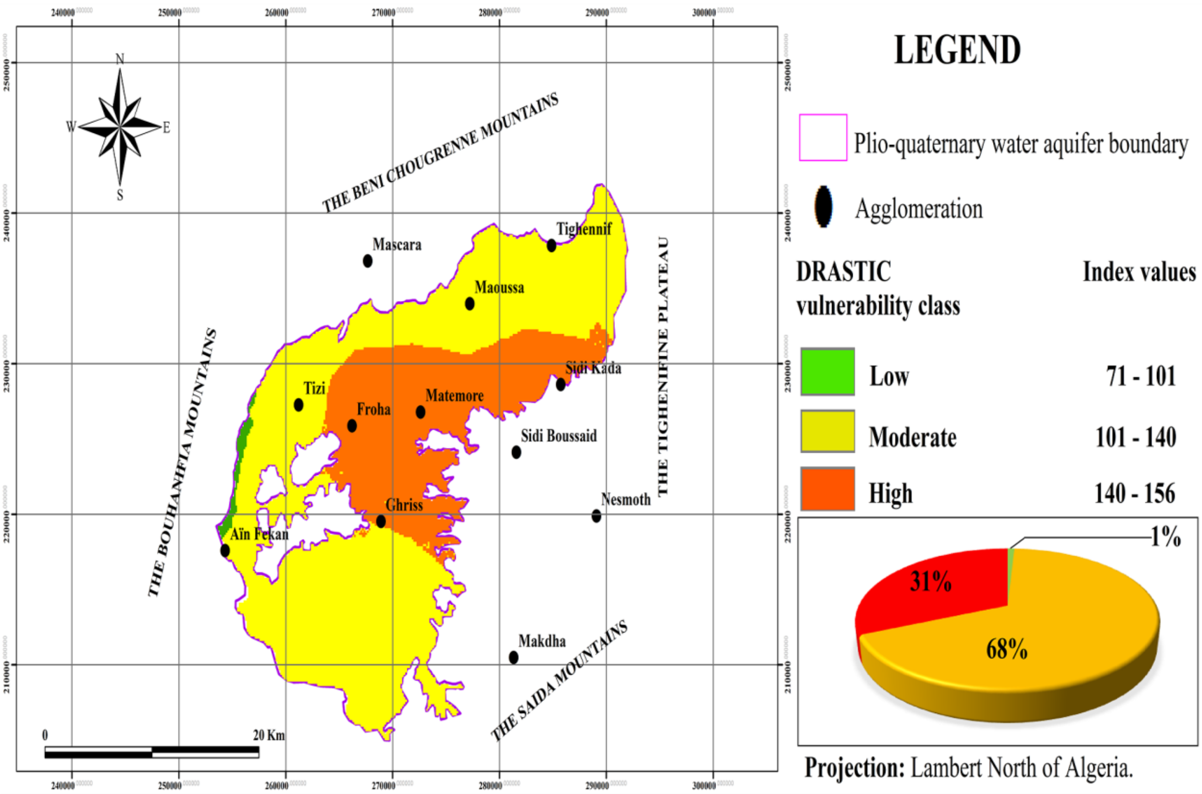

Figure 6. *DRASTIC vulnerability map of the Plio-Quaternary aquifer of the Ghriss plain*

- The **"Low"** vulnerability class is at 1% of the plain's alluvial aquifers. Index values range from 71 to 101, south of the Plio-Quaternary aquifer, i.e north of the town of Ain Fekan.
- The **"Moderate"** vulnerability class, occupies 68% of the plain's alluvial aquifer, with index values ranging from 101 to 140. This class is concentrated in the largest part of the plain's aquifer surface, at the north-northeast to north-north South circle.
- The **"High"** vulnerability class, covers 31% of the plains alluvial aquifer, with index values ranging from 140 to 156. This class is found around the central zone of the Ghriss plain Plio-Quaternary aquifer at Matmore, Froha, Ghriss, and north of Sidi-Kada.

4.2 Application of the DRASTIC-GOS method

These results of the DRASTIC-GOS indices agree with the vulnerability map in the study area in comparison with the classification drawn up by Engel et al., [9]. The values obtained by the proposed DRASTIC-GOS method range from 74 to 636. In the Plio-Quaternary aquifer, four (4) vulnerability classes can be found, located as follows in Figures 7 and 8:

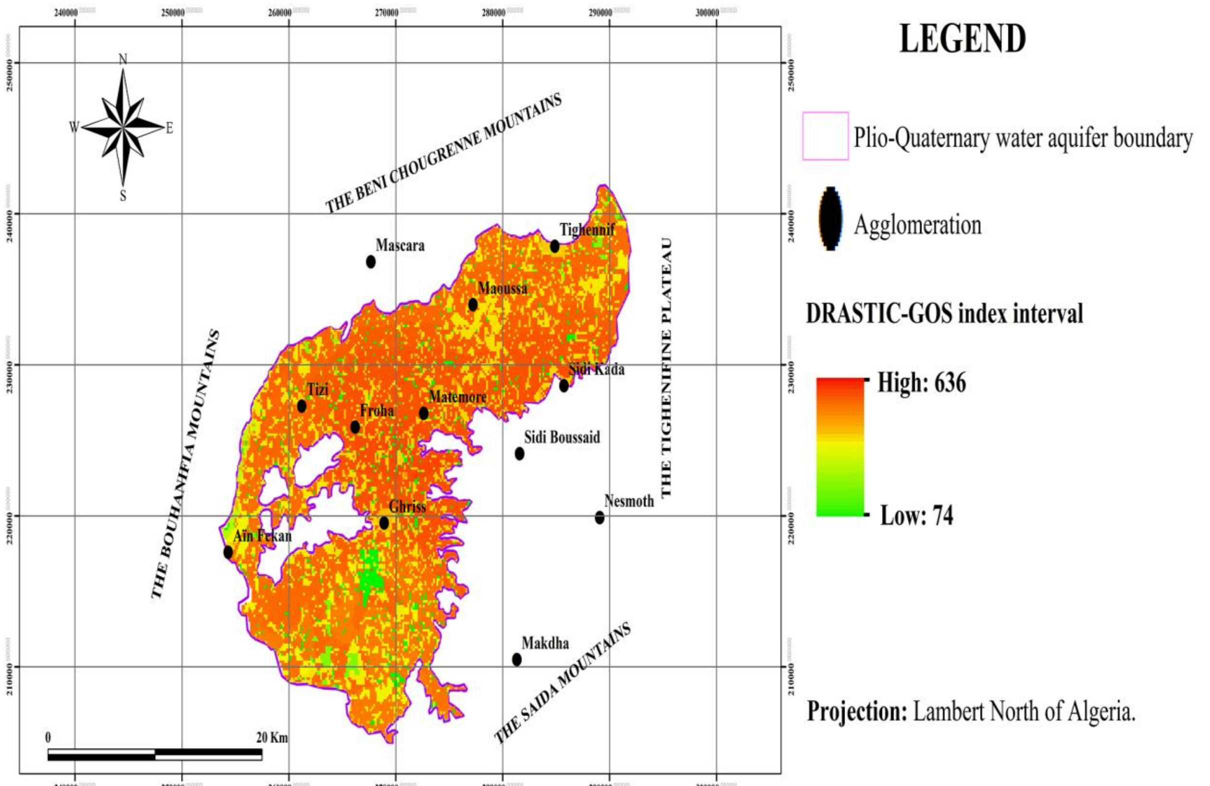

Figure 7. *Map of the interval of the DRASTIC-GOS index in the Plio-Quaternary of the Ghriss plain*

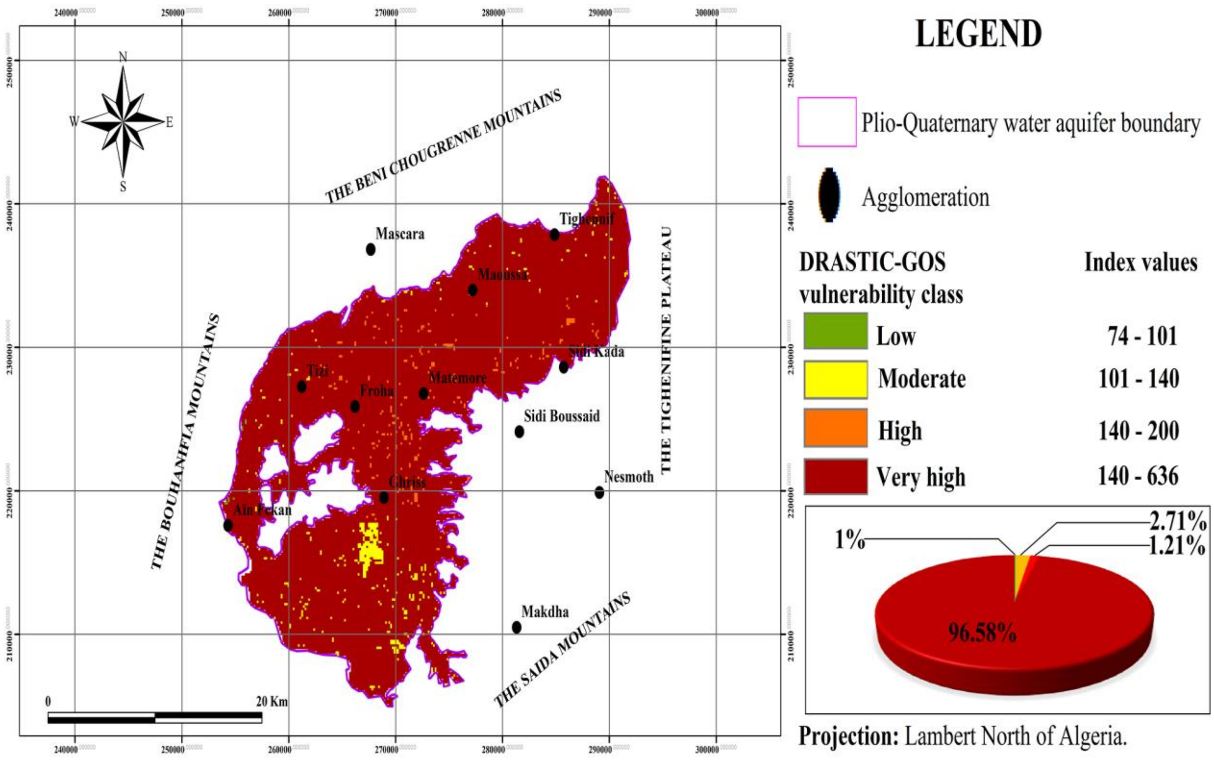

Figure 8. *DRASTIC-GOS vulnerability map of the Plio-Quaternary aquifer of the Ghriss plain*

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- **"Low"** vulnerability class, 0.04% of the Ghriss plain Plio-Quaternary water aquifer. Index values range from 74 to 101. This class is located in a few plots to the south of the study area.

- **"Moderate"** vulnerability class, covering 2.17% of the Ghriss plain aquifer. Index values range from 101 to 140, where this class covers a few north-northeast and north-northwest segments, to the east of the town of Tighennif and to the north of the town of Maoussa, as well as to the south of the study area.

- **"High"** vulnerability class, covering 1.21% of the Ghriss plain Plio-Quaternary water aquifer, with index values ranging from 140 to 20. This class is found in some of the central plots of the study area and to the east of the town of Sidi Kada.

- **"Very high"** vulnerability class for 96.58% of the Ghriss Plio-Quaternary aquifer. Indices in this class range from 200 to 636. It can be seen that the entire surface of the alluvial aquifer of the Ghriss plain is affected this vulnerability class.

5 VALIDATION

Confirmation of the DRASTIC and DRASTIC-GOS intrinsic vulnerability maps in the study area's Plio-Quaternary aquifer is based on groundwater analyses, the results of which are superimposed on the vulnerability maps for comparison with reality on the ground. To validate the pollution vulnerability mapping, we opted to monitor the presence of nitrates in the water of the alluvial aquifer, bearing in mind that the source of this pollution are essentially anthropogenic, particularly agricultural.

Of the 36 water samles taken from wells and boreholes across the Ghriss plain 80.6% of the samples indicated a groundwater nitrate concentration of between 10 and 50mg/l. These results confirm the low to medium vulnerability in relation to the accepted standards of 50mg/l [19]. On the other hand, 19.4% of the samples taken exceeded the admissible threshold in terms of nitrate content, with concentration ranging from 50 and 70mg/l. These values are found in the high to very-high vulnerability zone in figure 9 and 10.

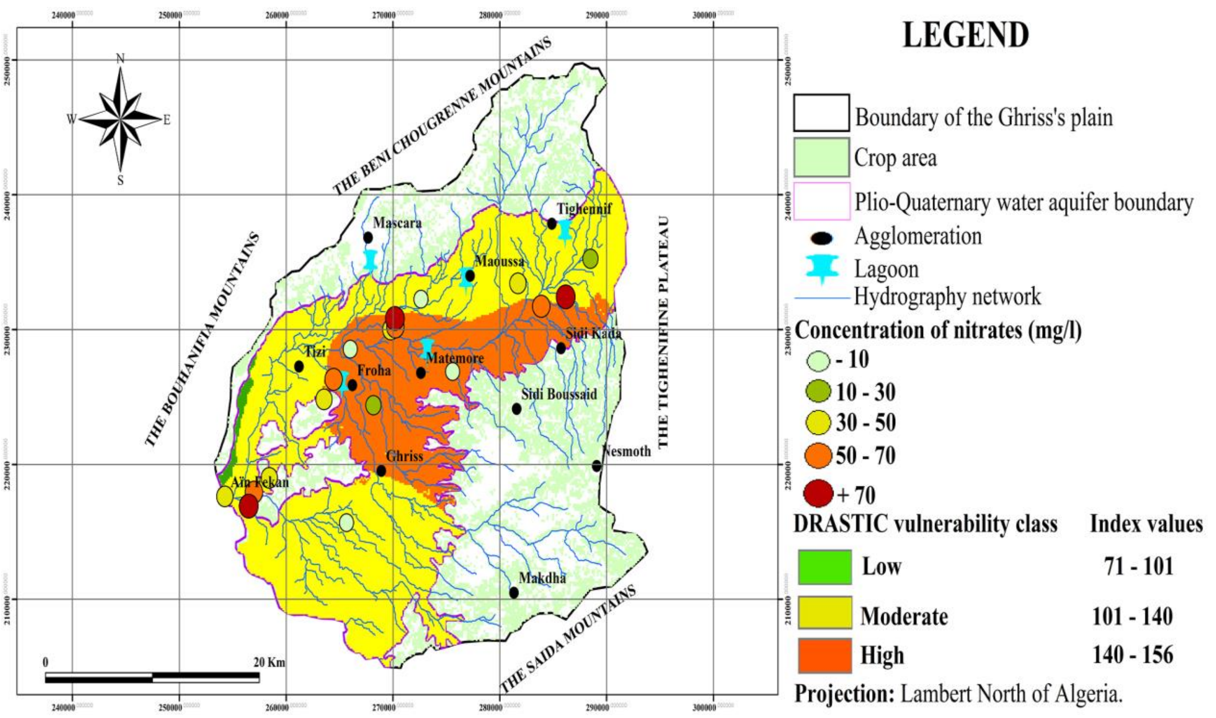

__Figure 9.__ Validation of the vulnerability of the Plio-Quaternary Ghriss aquifer (DRASTIC method)

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Thus, the DRASTIC vulnerability classification map, superimposed on sample concentration, highlights the predominance of the risks of concentration of water for human consumption, which are located where vulnerability is high, i.e. To the north-northeast, north-northwest and around the central zone (Froha, Ghriss) of the study area.

On the other hand, the DRASTIC-GOS vulnerability mapping, based on cross referenced nitrate results from samples, shows the risk of degradation of groundwater quality in the alluvial aquifer of the Ghriss plain, which is affected by very high vulnerability zones.

This confirms the value of coupling cartography with geospatial data analysis tools such as Geographic Information System (GIS). This performance is underlined by the comparison with water analyses through a representative sampling of the entire plain's alluvial groudwater and polluting activities, in particular nitrates, considered a real danger for consumers.

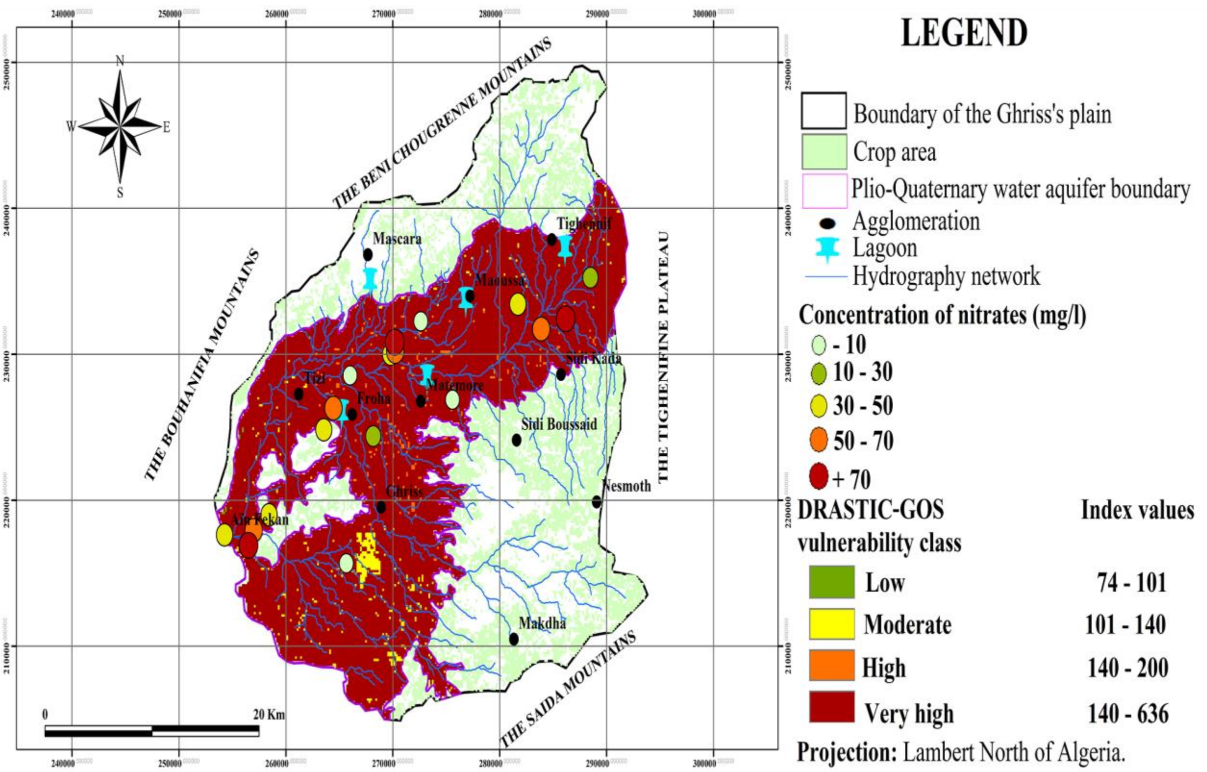

Figure 10. *Validation of the vulnerability of the Plio-Quaternary Ghriss aquifer (DRASTIC-GOS method)*

Finally, and taking into account the results of water analysis at the water points, in particular the concentration of nitrates, the comparison between the two methods reveals the performance of the DRASTIC-GOS model, which is closer to reality on the ground than Figure 11.

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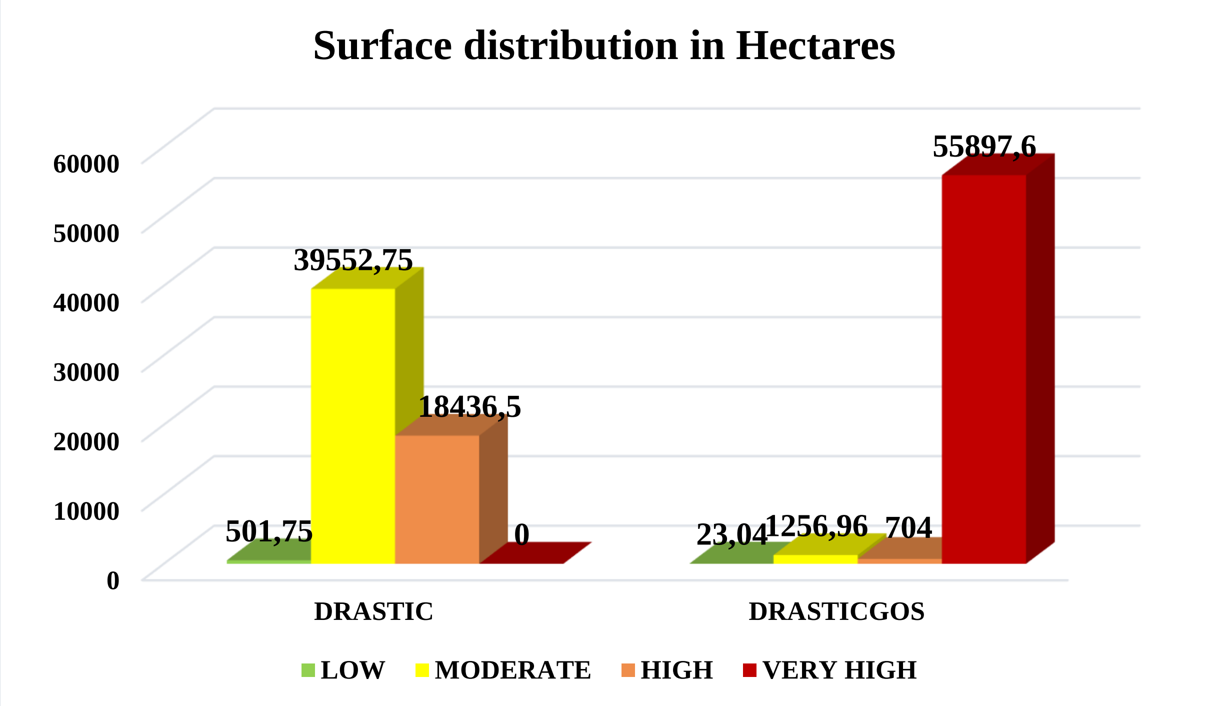

Figure 11. *Superficial distribution of the different vulnerability classes DRASTIC and DRASTIC-GOS*

6 CONCLUSION – RECOMMENDATION

The maps provided by DRASTIC method [9] indicate the possibility of heavy pollution in the central part of the Ghriss plain Plio-Quaternary water aquifer, where pumping is forced by irrigators. Application of the seven (7) thematic maps, compared with the DRASTIC index maps, reveals a high proportion of "Moderate" vulnerability classes (68%), located in a north-northeast to north-north south direction. The "High" vulnerability class (31%) corresponds to the eastern and central areas of the plain around Froha, Ghriss, Matmore, and north of Sidi Kada. Lastly, the "Low" vulnerability class (1%) is found in the southern part of the Plio-Quaternary aquifer and crosses the northern part of the town of Ain Fekan.

As for the maps obtained by applying the new DRASTIC-GOS method, the risks of vulnerability to pollution concern almost the entire Plio-Quaternary alluvial aquifer of the Ghriss plain, where extensive cultivation is practiced by irrigators using groundwater forcing. In fact, cross-referencing the nine (9) thematic maps, according to the Engel et al., [9] indices shows a high percentage of classes with "Very high" vulnerability (96.58%) located over most of the alluvial aquifer in the study area.

The "Moderate" vulnerability class (2.17%) corresponds to a few plots across the north-northeast, north-northwest and southern sub-zones of the plain. The "Low" vulnerability class (0.04%) is located in a few segments to the south of the plain. Finally, the negligible proportion of "High" vulnerability classes (0.04%) is located in the center of the study area. This pollution comes from a wide variety of sources, but first and foremost agricultural activities are the main culprits, due to their intensification and the consequences of the overuse of nitrogen products, which are leached and drained into the aquifer. Secondly, the low wastewater purification technology mean that aquifers are highly exposed to water pollution, as confirmed by the purification performance of most of the existing wastewater treatment plants on the Ghriss plain.

Validation by groundwater analysis, based on the nitrate concentration of certain wells, enabled us to highlight vulnerability maps using the DRASTIC method and more specifically, the DRASTIC-GOS method. In fact, the results obtained show that the nitrate concentration comply with irrigation standard, but not with drinking water standards. Hence the interest in of the DRASTIC-GOS vulnerability mapping approach, which is much more relevant. However, the latter requires multi-source data over a wide geospatial areas to produce effective results.

Recommendations include efficient, integrated management of groundwater resources to protect against undesirable effects, particularly the threat of irreversible nitrate pollution. Indeed, in view of the unrestrained encouragement of intensive agriculture, largely supported by the public authorities, it is strongly recommended to introduce rigorous controls on the use of nitrogen fertilizers. Similarly, after pre-treatment, primary treatment and secondary treatment, it is suggested that tertiary treatment be introduced to improve the quality of treated water, notably through the application of UV and drum filter techniques, with a view to better eliminating non-biodegradable pollutants such as nitrates. Finally, in the near future, it is planned to extend the vulnerability of the Ghriss aquifer to nitrate pollution to include a wider and more complete range of pollutants, while ensuring that control points are increased as far as the aquifer managers allow.

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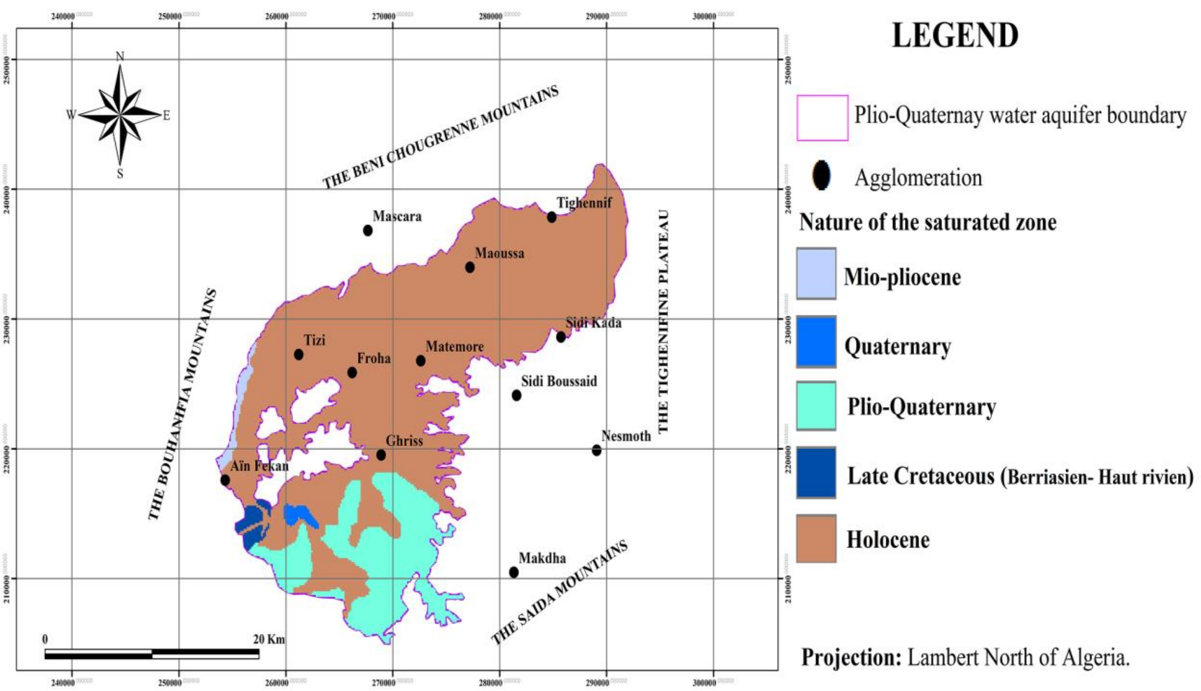
ANNEXES

Annexes 1. *Distribution of thematic maps of the intrinsic vulnerability of the plio-quaternary aquifer*



1a. *Nature of the saturated zone of the Ghriss alluvial aquifer*

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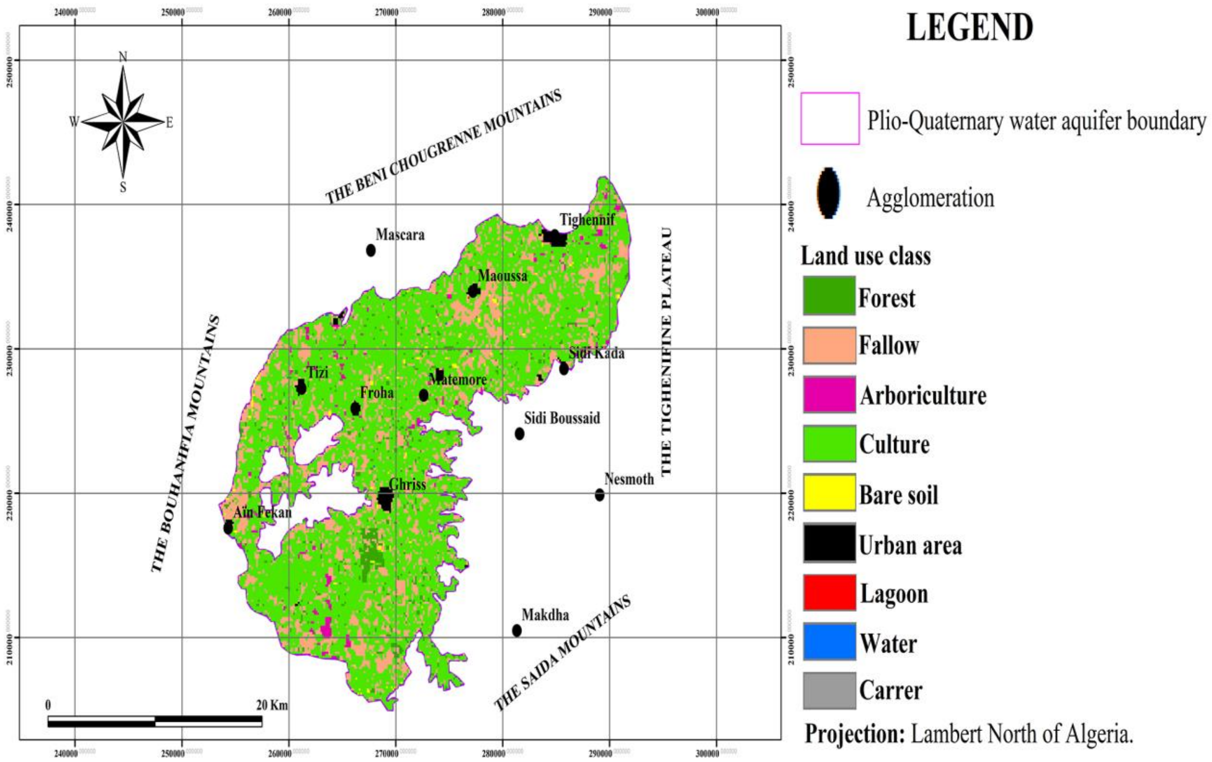
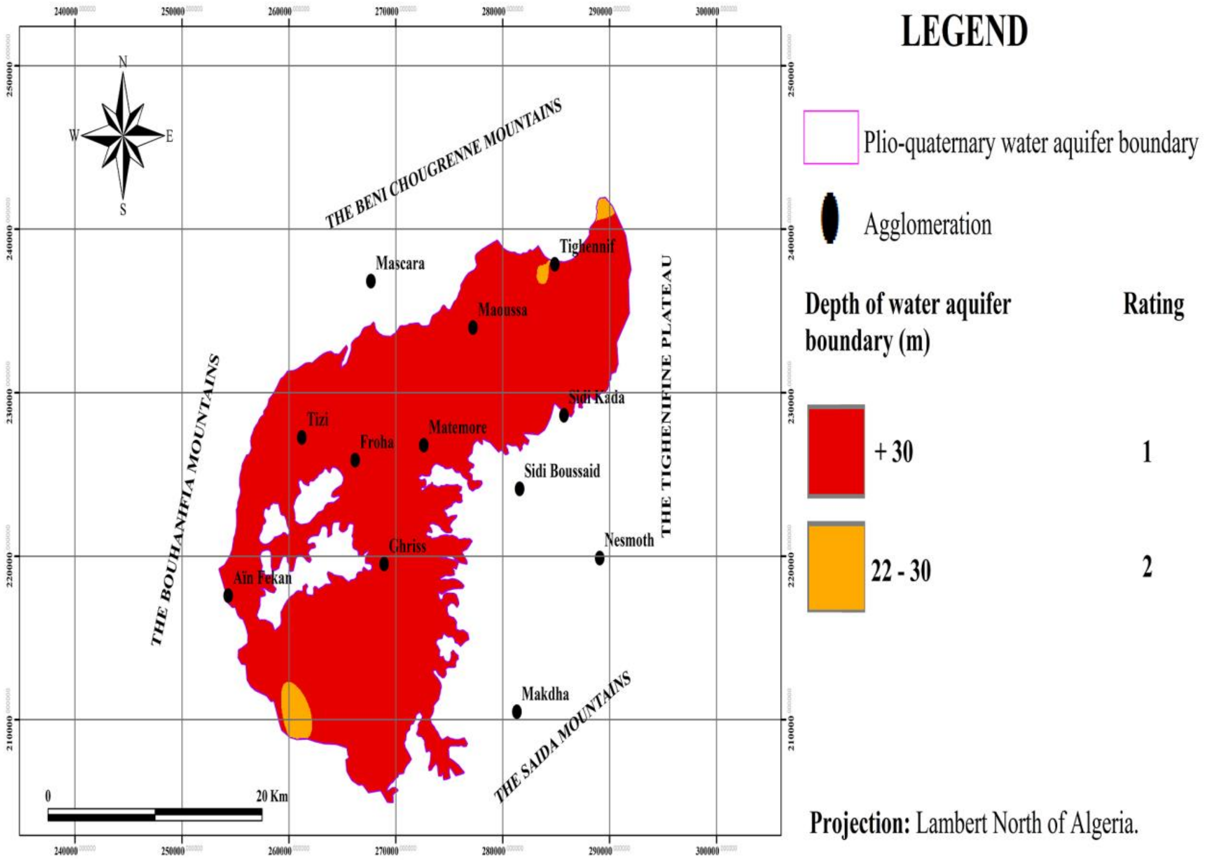
DOI 10.35180/gse-2024-0114



***1b.** Land us in the Ghriss alluvial aquifer*



***1c.** Depth of the Ghriss alluvial aquifer*

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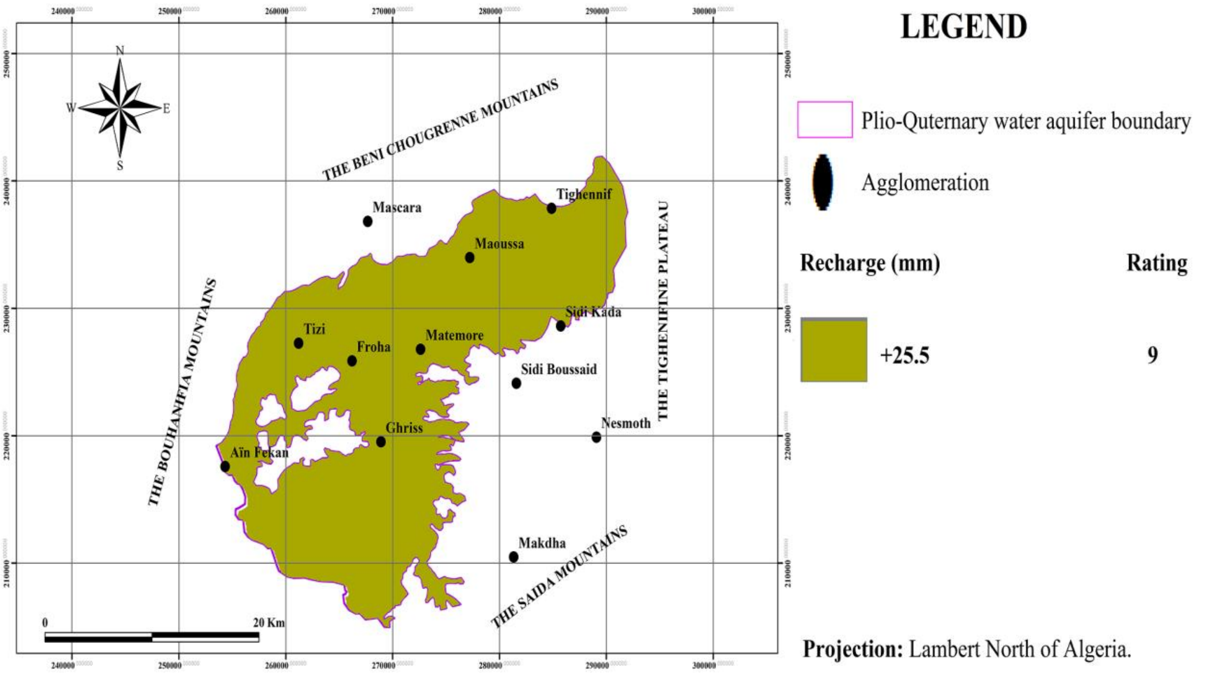
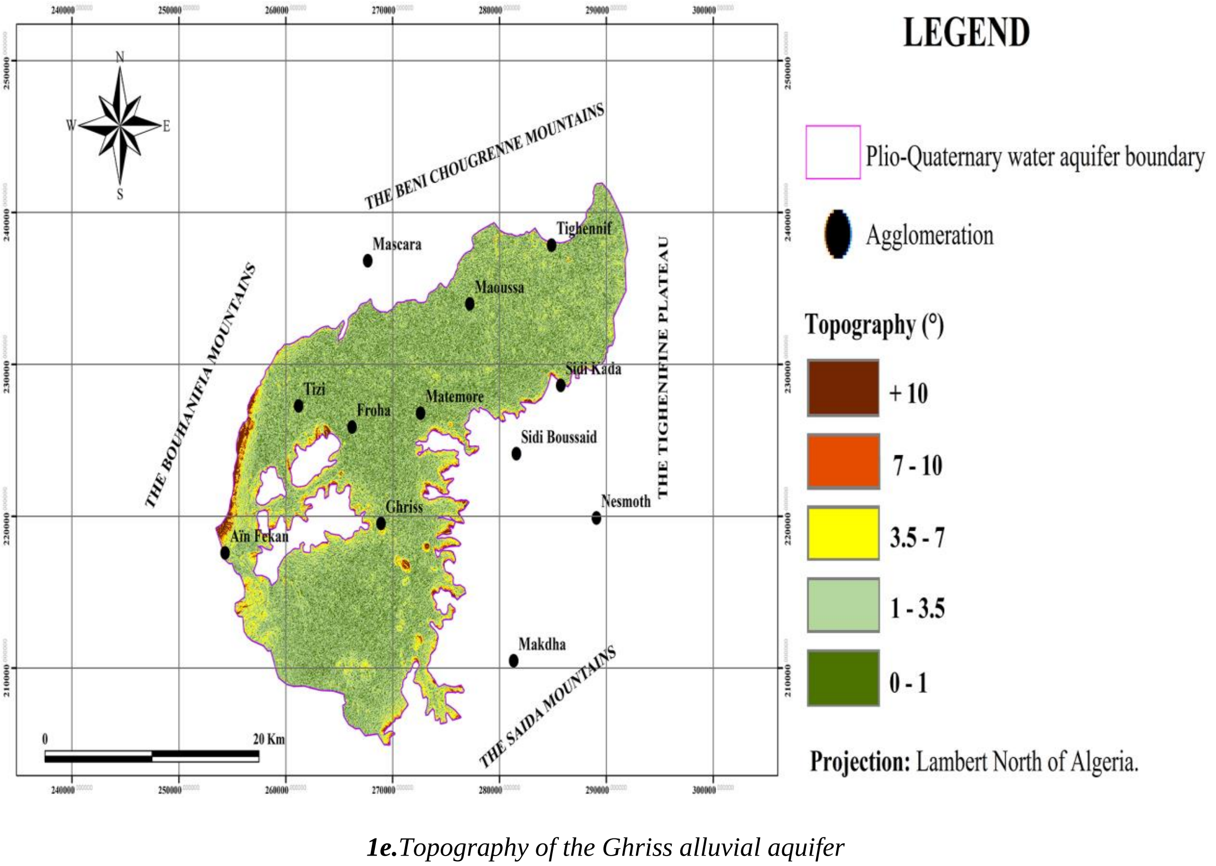
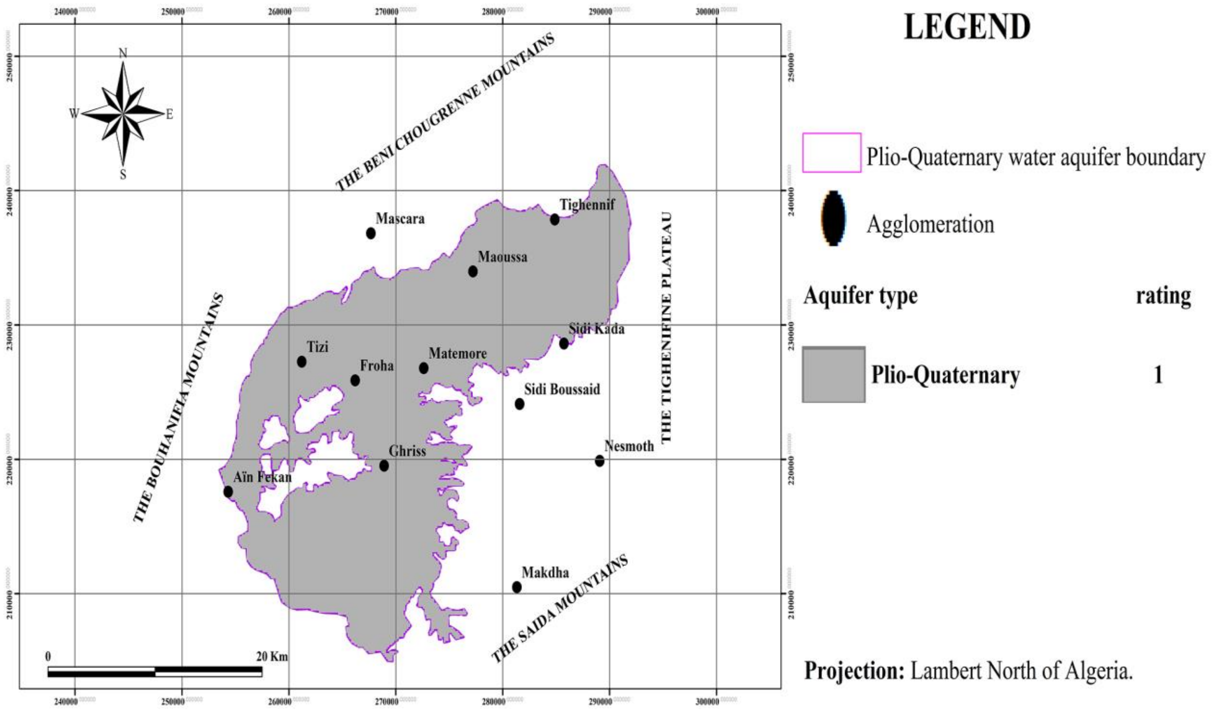
DOI 10.35180/gse-2024-0114



***1d.** Recharge of the Ghriss alluvial aquifer*



***1e.**Topography of the Ghriss alluvial aquifer*



1f. *Aquifer type of the Ghriss alluvial aquifer*